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NEWTON'S HYPOTHESES OF ETHER AND OF GRAVITATION FROM 1679 TO 1693.

I.

NEWTON'S letter to Boyle, referred to in the last article in this series, contained an extension of the views described in the "Hypothesis" of 1675, was written on February 28, 1679,¹ and was in fulfilment of a long deferred promise. This promise was, indeed, according to Newton, the chief reason for the communication of notions so "indigested" and unsatisfactory to himself. He added that, as it was only an "explication of qualities" that was desired by Boyle, he set down "his apprehensions in the form of suppositions."

"And first," continued Newton, "I suppose that there is diffused through all places an ethereal substance, capable of contraction and dilatation, strongly elastic, and, in a word, much like air in all respects, but far more subtle.

"2. I suppose this ether pervades all gross bodies, but yet so as to stand rarer in their pores than in free spaces, and so much the rarer as their pores are less; and this I suppose (with others) to be the cause why light incident on those bodies is refracted towards the perpendicular; why two well-polished metals cohere in a receiver exhausted of air; why quick-silver stands sometimes up to the top of a glass pipe, though much higher than thirty inches; and

¹ Reproduced in *Horsley*, Vol. IV, pp. 385-394; and Brewster, *op. cit.*, Vol. I, pp. 409-419; cf. pp. 145-146. Cf. also Birch, *op. cit.*, Vol. III, p. 261; Rosenberger, *op. cit.*, pp. 124-127.

one of the main causes why the parts of all bodies cohere; also the cause of filtration, and of the rising of water in small glass pipes above the surface of the stagnating water they are dipped into; for I suspect the ether may stand rarer, not only in the insensible pores of bodies, but even in the very sensible cavities of those pipes; and the same principle may cause menstruums to pervade with violence the pores of the bodies they dissolve, the surrounding ether as well as the atmosphere pressing them together.

"3. I suppose the rarer ether within bodies and the denser without them not to be terminated in a mathematical superficies, but to grow gradually into one another; the external ether beginning to grow rarer and the internal to grow denser at some little distance from the superficies of the body, and running through all intermediate degrees of density in the intermediate spaces; and this may be the cause why light, in Grimaldi's experiment, passing by the edge of a knife or other opaque body, is turned aside and as it were refracted, and by that refraction makes several colors. Let² ABCD be a dense body, whether opaque or transparent, EFGH the outside of the uniform ether which is within it, IKLM the inside of the uniform ether which is without it; and conceive the ether which is between EFGH and IKLM to run through all intermediate degrees of density between that of the two uniform ethers on either side. This being supposed, the [parallel] rays of the sun SB, SK, which pass by the edge of this body between B and K, ought, in their passage through the unequally dense ether there, to receive a ply from the denser ether which is on that side toward K, and that the more by how much they pass nearer to the body, and thereby to be scattered through the space PQRST [PQRST being a line cutting the set of rays from S], as by experience they are found to be. Now the space between the limits EFGH and

²The figure to which this refers is quite easily drawn.

IKLM, I shall call 'the space of the ether's graduated rarity.'

"4. When two bodies moving toward one another come near together, I suppose the ether between them to grow rarer than before, and the spaces of its graduated rarity to extend further from the superficies of the bodies toward one another; and this, by reason that the ether cannot move and play up and down so freely in the narrow passage between the bodies, as it could before they came so near together. . . . I do not think the spaces of graduated ether have precise limits, but rather decay insensibly, and, so decaying, extend to a much greater distance than can easily be believed or need be supposed.

"5. Now, from the fourth supposition it follows that when two bodies approaching one another come so near together as to make the ether between them begin to rarefy, they will begin to have a reluctance from being brought nearer together and an endeavor to recede from one another; which reluctance and endeavor will increase as they come nearer together because thereby they cause the interjacent ether to rarefy more and more. But at length, when they come so near together that the excess of pressure of the external ether which surrounds the bodies above that of the rarefied ether which is between them is so great as to overcome the reluctance which the bodies have from being brought together, then will that excess of pressure drive them with violence together and make them adhere strongly to one another, as was said in the second supposition. . . .³ Now, hence I conceive it is chiefly that a fly walks on water without wetting her feet, and consequently without touching the water; that two polished pieces of glass are not without pressure brought

³ "This deduction of molecular attraction and repulsion," said Rosenberger (*op. cit.*, p. 125), "shows clearly how far Newton then was from his system of primitive or elementary forces of all matter, which only differ by the law of their actions."

to contact, no, not though the one be plane and the other a little convex; that the particles of dust cannot by pressing be made to cohere, as they would do if they did but fully touch; that the particles of tingeing substances and salts dissolved in water do not of their own accord concrete and fall to the bottom, but diffuse themselves all over the liquor, and expand still more if you add more liquor to them. Also, that the particles of vapors, exhalations, and air do stand at a distance from one another, and endeavor to recede as far from one another as the pressure of the incumbent atmosphere will let them; for I conceive the confused mass of vapors, air, and exhalations, which we call the atmosphere to be nothing else but the particles of all sorts of bodies of which the earth consists, separated from one another and kept at a distance by the said principle."

By these principles Newton then explained the actions of menstruums upon bodies, the phenomena of effervescence and ebullition, and the transmutation of gross and compact substances into aëreal ones by heat. Lastly, he shortly described a conjecture about the cause of gravity, which is quoted in § IX of the article on "The Principles of Mechanics with Newton from 1666 to 1679" in the number of this magazine for April, 1914.

II.

From Newton's papers of 1672, 1675 and 1679, Thomas Young was led, in 1801, to the view that Newton had abandoned the corpuscular or emission-theory of light for what is nearly the undulatory theory; and Brewster⁴ tried to show that Newton's mature views were in favor of the emission-theory, by quoting, in particular, the 27th query to the edition of the *Opticks* published in 1706. This query will be quoted below. Young extracted some passages from Newton's earlier writings which, according to him,

⁴ *Op. cit.*, Vol. I, pp. 146-149.

cannot be supposed to militate against his maturer judgment. Brewster⁵ also quoted from a letter written by Leibniz to Huygens on April 26, 1694, stating, on the authority of Fatio d'Huillier, that Newton was "more than ever led to believe that light consists of bodies which come actually to us from the sun, ..." A very useful summary of the scheme of the world which Newton seems to have favored was given by Whittaker⁶ from a comparison of the works of 1672, 1675, 1679, the Scholium at the end of the *Principia* of 1687, and Queries 18, 19, 20, 21, 23, 29 at the end of the *Opticks*. We will next turn our attention to the treatment of ether and the question of the nature of gravitation in the *Principia*.

III.

In the Scholium at the end of the eleventh Section of the first Book of the *Principia*,⁷ Newton said:

"I here use the word attraction in general for any endeavor whatever made by bodies to approach each other; whether that endeavor arise from the action of the bodies themselves as tending mutually to, or agitating each other by spirits emitted; or whether it arises from the action of the ether or of the air or of any medium whatever, whether corporeal or incorporeal, any how impelling bodies placed therein toward each other. In the same general sense I use the word impulse, not defining in this treatise the species or physical qualities of forces, but investigating the quantities and mathematical proportions of them; as I observed before in the definitions. . . ."⁸

⁵ *Ibid.*, pp. 149-150.

⁶ *Op. cit.*, pp. 17-21.

⁷ Cf. Rosenberger, *op. cit.*, p. 193.

⁸ "Vocem attractionis hic generaliter usurpo pro corporum conatu quocunque accedendi ad invicem, sive conatus iste fiat ab actione corporum vel se mutuo petentium, vel per Spiritus emissos se invicem agitantium, sive is ab actione Aetheris aut Aeris mediive cujuscunque seu corporei seu incorporei oriatur corpora innatantia in se invicem utcunque impellentis. Eodem sensu generali usurpo vocem impulsus, non species virium et qualitates physicas, sed quantitates et proportiones Mathematicas in hoc Tractatu expendens: ut in Definitionibus explicui" (*Principia*, 1687, pp. 191-192).

The fourteenth Section of the first Book deals with the motion of very small bodies attracted by central forces toward the parts of a large body. According to Rosenberger,⁹ this Section, "which does not in the least fit into a place in the investigations of the previous Sections, was only inserted to express the altered character of Newton's optical views. In fact, the Section reduces the causes of refraction and diffraction of light to the new notions of attractive forces acting at a distance, and clearly shows that Newton had overcome his tendency toward theories of the ether. In this Section, too, we find the first traces of the idea of the 'fits of easy transmission or reflexion' of light, which were later on so systematically used for the explanation of the colors of thin plates and of the phenomena of diffraction." However, though the analogy of light with streams of corpuscles was indicated, Newton did not commit himself to any theory of light based on this. Indeed, in the *Scholium* to the 96th proposition, which is one of those in this Section, Newton said:

"These attractions bear a great resemblance to the reflections and refractions of light, made in a given ratio of the secants, as was discovered by Snell; and consequently in a given ratio of the sines, as was exhibited by Descartes. For it is now certain from the phenomena of Jupiter's satellites confirmed by the observations of different astronomers, that light is propagated in succession, and requires about seven or eight minutes to travel from the sun to the earth. Moreover the rays of light that are in our air (as lately was discovered by Grimaldi, by the admission of light into a dark room through a small hole, which I have also tried) in their passage near the angles of bodies whether transparent or opaque (such as the circular and rectangular edges of gold, silver and brass coins, or of knives or broken pieces of stone or glass) are bent

⁹ *Op. cit.*, p. 197.

or inflected round those bodies as if they were attracted to them; and those rays which in their passage come nearest to the bodies are the most inflected, as if they were most attracted; which thing I myself have also carefully observed. . . . Therefore, because of the analogy there is between the propagation of the rays of light and the motion of bodies, I thought it not amiss to add the following propositions for optical uses; not at all considering the nature of the rays of light, or inquiring whether they are bodies or not; but only determining the trajectories of bodies which are extremely like the trajectories of the rays."¹⁰

"With the second Book of the *Principia*," said Rosenberger,¹¹ "Newton began a wholly new series of investigations. Up till then he had only treated of the motion of bodies in empty space, without considering any resistance to which these bodies might be subjected. There was hardly any occasion for a conflict with the then dominant physics of Descartes, which started from the hypothesis of a plenum. But when Newton passed over to the determination of the modifications which the motions of bodies experience on the resistance of a medium which fills space, his theorems had either to agree with or contradict the theories of Descartes."

¹⁰ "Harum attractionem haud multum dissimiles sunt Lucis reflexiones et refractiones, factae secundum datam secantium rationem, ut invenit *Snellius*, et per consequens secundum datam Sinum rationem, ut exposuit *Cartesius*. Namque Lucem successive propagari et spatio quasi decem minutorum primorum a Sole ad Terram venire, jam constat per Phaenomena Satellitum *Jovis*, Observationibus diversorum Astronomorum confirmata. Radii autem in aere existentes (ubi dudum *Grimaldus*, luce per foramen in tenebrosus cubiculum admissa, invenit, et ipse quoque expertus sum) in transitu suo prope corporum vel opacorum vel perspicuorum angulos (quales sunt nummorum ex auro, argento et aere cusorum termini rectanguli circulares, et cultrorum, lapidum aut fractorum vitrorum acies) incurvantur circum corpora, quasi attracti in eadem; et ex his radiis, qui in transitu illo propius accedunt ad corpora incurvantur magis, quasi magis attracti, ut ipse etiam diligenter observavi. . . . Igitur ob analogiam quae est inter propagationem radiorum lucis et progressum corporum, visum est Propositiones sequentes in usus opticos subungere interea de natura radiorum (utrum sint corpora necne) nihil omnino disputans, sed trajectories corporum trajectoryis radiorum persimiles solummodo determinans" (*Principia*, 1687, pp. 231-232).

¹¹ *Op. cit.*, p. 198.

¹² This Scholium was first added in the edition of 1713. The passage in question is: "Denique cum receptissima Philosophorum aetatis hujus opinio

Toward the end of the general Scholium¹² at the end of the sixth section, Newton said:

"Since it is the opinion of some that there is a certain ethereal medium extremely rare and subtle which freely pervades the pores of all bodies, and from such a medium so pervading the pores of bodies some resistance must needs arise, in order to try whether the resistance which we experience in bodies in motion be made upon their outward superficies only, or whether their internal parts meet with any considerable resistance upon their superficies, I thought of the following experiment. . . ."

The eighth Section of the second Book is on motion propagated through fluids. The theory that Newton here developed of periodic vibrations in an elastic medium was in connection with the explanation of sound, but had, of course, a great influence on the formation of the undulatory theory. "The last propositions," said Newton in the Scholium at the end of this Section, "respect the motions of light and sounds. For since light is propagated in right lines, it is certain that it cannot consist in action alone. As to sounds, since they arise from tremulous bodies, they can be nothing else but pulses of the air propagated through it. . . ." ¹³

In the first edition of the *Principia*, the third Corollary to the sixth Proposition of the third Book is: "And so there is necessarily a vacuum. For if all spaces were full, the specific gravity of the fluid with which the region of the air is filled, on account of the extreme density of the

sit, Medium quoddam aethereum et longe subtilissimum extare, quod omnes omnium corporum poros et meatus liberrime permeet; a tali autem Medio per corporum poros fluente resistentia oriri debeat: ut tentarem an resistentia, quam in motis corporibus experimur, tota sit in eorem externa superficie, an vero partes etiam internae in superficiebus propriis resistentiam notabilem sentiant, excogitavi experimentum tale. . . ." (*Principia*, 1713, p. 292).

¹³ "Spectant Propositiones novissimae ad motum Lucis et Sonorum. Lux enim cum propagetur secundum lineas rectas, in actione sola (per Prop. XLI. et XLII.) consistere nequit. Soni vero propterea quod a corporibus tremulis oriuntur, nihil aliud sunt quam aeris pulses propagati, per Prop. XLIII" (*Principia*, 1687, p. 369).

matter, would fall nothing short of the specific gravity of quicksilver or gold or any other very dense body; and therefore neither gold nor any other body could descend in air. For bodies do not descend in fluids unless they are specifically heavier than the fluid."¹⁴

On the subject of this passage, it seems to be the best thing to depart somewhat from the chronological order, and consider the comments made on this point in the correspondence between Roger Cotes and Newton which took place when, in 1712, Cotes was preparing the second edition of the *Principia*.

In the postscript of his letter of February 16, 1712, to Newton, Cotes said:¹⁵

"Before I conclude this letter, I will take notice of an objection which may seem to be against the third Corollary of Proposition VI of Book III: *Itaque Vacuum necessario datur etc.* Let us suppose two globes A and B of equal magnitude to be perfectly filled with matter without any interstices of void space; I would ask the question whether it be impossible that God should give different forces of inertia to these globes. I think it cannot be said that they must necessarily have the same or an equal force of inertia. Now, you do all along in your philosophy, and I think very rightly, estimate the quantity of matter by the force of inertia, and particularly in this sixth Proposition, in which no more is strictly proved than that the gravities of all bodies are proportional to their forces of inertia. It is possible, then, that the equal spaces possessed by the globes A and B may be both perfectly filled with matter so that no void interstices may remain and yet that the quantity

¹⁴ "Itaque Vacuum necessario datur. Nam si spatia omnia plena essent, gravitas specifica fluidi quo regio aeris impleteretur, ob summam densitatem materiae, nil cederet gravitati specificaе argenti vivi, vel auri, vel corporis alterius cujuscunque densissimi; et propterea nec aurum neque aliud quodcunque corpus in aere descendere posset. Nam corpora in fluidis, nisi specificè graviora sint, minime descendunt" (*Principia*, 1687, p. 411).

¹⁵ Edleston, *op. cit.*, pp. 65-66.

of matter in each space shall not be the same. Therefore, when you define or assume the quantity of matter to be proportional to its force of inertia, you must not at the same time define or assume it to be proportional to the space which it may perfectly fill without any void interstices unless you hold it impossible for the two globes A and B to have different forces of inertia. Now, in the third Corollary, I think you do in effect assume both these things at once."

In his reply of February 19, Newton said:¹⁶

"For obviating the objection you make against the third Corollary of Prop. VI, Book III, you may add to the end of that Corollary these words: 'Hoc ita se habebit si modo materia sit gravitati suae proportionalis et insuper impenetrabilis adeoque ejusdem semper densitatis in spatiis plenis.'"

Cotes replied on February 23 that this addition did not seem to him to come fully up to the objection. After quoting Newton's words, he continued:¹⁷

"Now, by *materia* you mean the quantity of matter, and this you always estimated by its force of inertia, and therefore it will be supposed that you do in this place so estimate it; but if *materia* be here taken in this sense the objection will not be obviated. Perhaps with some alteration of my words, which you may be pleased to make, the addition may stand thus: 'Hoc ita se habebit si modo magnitudo vel extensio materiae in spatiis plenis, sit semper proportionalis materiae quantitati et vi Inertiae atque adeo vi gravitatis: nam per hanc Propositionem constituit quod vis inertiae et quantitas materiae sit ut ejusdem gravitas.'"

Newton replied on February 26:¹⁸

"I have reconsidered the third Corollary of the sixth Proposition. And, for preventing the cavils of those who are ready to put two or more sorts of matter, you may

¹⁶ *Ibid.*, pp. 67-68.

¹⁷ *Ibid.*, pp. 68-69.

¹⁸ *Ibid.*, p. 73.

add these words to the end of the Corollary: 'Vim inertiae proportionalem esse gravitati corporis constitit per experimenta pendulorum. Vis inertiae oritur a quantitate materiae in corpore ideoque est ut ejus massa. Corpus consensatur per contractionem pororum, et poris destitutum (ob impenetrabilitatem materiae) non amplius condensari potest; ideoque in spatiis plenis est ut magnitudo spatii. Et concessis hisce tribus Principiis Corollarium valet.' "

But Cotes again wrote on February 28:¹⁹

"I have looked over your new addition to the third Corollary of the sixth Proposition, but I am not yet satisfied as to the difficulty, unless you will be pleased to add that it is true upon this concession that the primigenial particles out of which the world may be supposed to have been framed (concerning which you discourse at large in the additions to your *Optice*, p. 343 *et. seqq.*) were all of them created equally dense, that is (as I would rather speak) have all the same force of inertia in respect of their real magnitude or extension in full space. I call this a concession, because I cannot see how it may be certainly proved either *a priori* by bare reasoning from the nature of the thing, or be inferred from experiments. I am not certain whether you do not yourself allow the contrary to be possible. Your words seem to mean so in page 347, line 5, of the *Optice*: 'Forte etiam et diversis densitatibus diversisque viribus.' "

Lastly, Newton replied on March 18:²⁰

"I thank you for explaining your objection to the third Corollary of the sixth Proposition. That Corollary and the next may be put in this manner." After that part of the third Corollary which is quoted above, Newton added the words:

"And if the quantity of matter in a given space can, by

¹⁹ *Ibid.*, pp. 75-76.

²⁰ *Ibid.*, p. 80.

any rarefaction, be diminished, what should hinder a diminution to infinity?

"Cor. 4. If all the solid particles of all bodies are of the same density, nor can be rarefied without pores, a void space or vacuum must be granted. By bodies of the same density I mean those whose forces of inertia are in the proportion of their bulks."

What was the fourth Corollary in the first edition then became the fifth in the second edition. It is:

"The power of gravity is of a different nature from the power of magnetism. For the magnetic attraction is not as the matter attracted. Some bodies are attracted more by the magnet, others less; most bodies not at all. The power of magnetism, in one and the same body, may be increased and diminished; and is sometimes far stronger, for the quantity of matter, than the power of gravity; and in receding from the magnet, decreases not in the duplicate, but almost in the triplicate proportion of the distance, as nearly as I could judge from some rude observations."²¹

This is the form in which these Corollaries are given in the second edition of the *Principia*.²²

To the last passage Edleston added the note:

"At the meeting of the Royal Society two days afterwards, Newton proposed that Halley and Hauksbee should

²¹ "Corol. 3. Spatia omnia non sunt aequaliter plena. Nam si spatia omnia aequaliter plena essent, gravitas specifica fluidi quo regio aeris imple-retur, ob summam densitatem materiae, nil cederet gravitati specificae argenti vivi, vel auri, vel corporis cujuscunque densissimi, et propterea nec aurum neque aliud quodcunque corpus in aere descendere posset. Nam corpora in fluidis, nisi specificè graviora sint, minime descendunt. Quod si quantitas materiae in spatio dato per rarefactionem quamcunque diminui possit, quidni diminui possit in infinitum? Corol. 4. Si omnes omnium corporum particulae solidae sint ejusdem densitatis neque absque poris rareferi possint, Vacuum datur. Ejusdem densitatis esse dico quarum vires inertiae sunt ut magni-tudines. Corol. 5. Vis gravitatis diversi est generis a vi magnetica. Nam attractio magnetica non est ut materia attracta. Corpora aliqua magis trahun-tur, alia minus, plurima non trahuntur. Et vis magnetica in uno et eodem corpore intendi potest et remitti,, estque nonnunquam longe major pro quan-titate materiae quam vis gravitatis, et in recessu a Magnete decrescit in ra-tione distantiae non duplicata, sed fere triplicata, quantum ex crassis quibus-dam observationibus animadvertere potui."

²² P. 368.

make experiments with 'the great loadstone,' in order to find the true law of the decrease, which he believed would be nearer the cubes than the squares. See also *Journal Book*, March 27, April 3, May 15, June 12, 26, *Phil. Trans.*, July-September 1712, June-August 1715. Coulomb's experiments with a torsion balance first established the law to be as the squares."

IV.

The third of "The Rules of Reasoning in Philosophy" (*Regulae philosophandi*) which first appeared in the second edition of the *Principia* and were placed near the beginning of the third Book is that those qualities of bodies which admit neither intension nor remission of degrees and which are found to belong to all bodies within the reach of our experiments are to be reckoned as the universal qualities of all bodies whatever. At the end of this rule, Newton said:

"Lastly, if it universally appears, by experiments and astronomical observations that all bodies about the earth gravitate toward the earth, and that in proportion to the quantity of matter which they severally contain; that the moon likewise, according to the quantity of its matter, gravitates toward the earth; that on the other hand our sea gravitates toward the moon; and all the planets mutually one toward another; and the comets in like manner toward the sun; we must, in consequence of this rule, universally allow that all bodies whatever are endowed with the principle of mutual gravitation. For the argument from the appearances concludes with more force for the universal gravitation of all bodies, than for their impenetrability; of which among those in the celestial regions, we have no experiments, nor any manner of observation."²⁸

In the third edition of 1725, Newton added:

²⁸"Denique si corpora omnia in circuitu Terrae gravia esse in Terram, idque pro quantitate materiae in singulis, et Lunam gravem esse in Terram

"Not that I affirm gravity to be essential to bodies. By their innate force (*vis insita*) I mean nothing but their force of inertia. This is immutable. Their gravity is diminished as they recede from the earth."²⁴

In a general Scholium which first appeared in the second edition and at the end, Newton paid a tribute of some length to the Deity. "This most beautiful system," it began, "of the sun, planets and comets, could only proceed from the counsel and dominion of an intelligent and powerful being." Then Newton went on to say:

"This Being governs all things, not as the soul of the world, but as Lord over all. . . . The true God is a living, intelligent and powerful being; . . . He is eternal and infinite, omnipotent and omniscient; . . . He is not Eternity or Infinity, but eternal and infinite; he is not Duration or Space, but he endures and is present. . . . He is omnipresent, not virtually only but also substantially; for virtue cannot subsist without substance. In him are all things contained and moved; yet neither affects the other: God suffers nothing from the motion of bodies; bodies find no resistance from the omnipresence of God. . . ."

Six months after the completion of the second edition of the *Principia*, which was published in 1713 under the editorship of Roger Cotes, Newton sent the following addition to Cotes, which first appeared in the third edition of 1725:

"Blind metaphysical necessity, which is certainly the same always and everywhere, could produce no variety of things. All that diversity of natural things which we find

pro quantitate materiae suae, et vicissim mare nostrum grave esse in Lunam, et Planetas omnes graves esse in se mutuo et Cometarum similem esse gravitatem, per experimenta et observationes Astronomicas universaliter constet: dicendum erit per hanc Regulam quod corpora omnia in se mutuo gravitant. Nam et fortius erit argumentum ex Phaenomenis de gravitate universali, quam de corporum impenetrabilitate: de qua utique in corporibus Coelestibus nullum experimentum, nullam prorsus observationem habemus" (*Principia*, 1713, p. 358).

²⁴ Cf. Rosenberger, *op. cit.*, pp. 212-213.

sued to different times and places could arise from nothing but the ideas and will of a Being necessarily existing."²⁵

"This," said Rosenberger, "almost looks as if Newton here wished to state clearly that gravity is a final cause which was directly implanted by God in all matter. But the following sentences contradict this." Then Rosenberger quoted the well-known words from the second edition:

"Hitherto we have explained the phenomena of the heavens and of our sea by the power of gravity, but have not yet assigned the cause of this power. This is certain, that it must proceed from a cause that penetrates to the very centers of the sun and planets without suffering the least diminution of its force; that operates, not according to the quantity of the surfaces of the particles upon which it acts, (as mechanical causes do,) but according to the quantity of the solid matter which they contain, and propagates its virtue on all sides, to immense distances, decreasing always in the duplicate proportion of the distances. . . . But hitherto I have not been able to discover the cause of those properties of gravity from phenomena, and I frame no hypotheses. For whatever is not deduced from the phenomena, is to be called a hypothesis; and hypotheses, whether metaphysical or physical, whether of occult qualities or mechanical, have no place in experimental philosophy. In this philosophy particular propositions are inferred from the phenomena, and afterwards rendered general by induction. Thus it was that the impenetrability, the mobility, and the impulsive force of bodies, and the laws of motion and of gravitation,

²⁵ "Elegantissima haecce Solis, Planetarum et Cometarum compages non nisi consilio et dominio Entis intelligentis et potentis oriri potuit. . . . Hic omnia regit, non ut Anima mundi, sed ut universorum Dominus; . . . Et ex dominatione vera sequitur, Deum verum esse vivum, intelligentem et potentem; . . . Aeternus est et *Infinitus*, *Omnipotens* et *Omnisciens*. . . . Non est aeternitas vel infinitas, sed durat et adest. . . . Omnipraesens est non per virtutem solam,

were discovered. And to us it is enough that gravity does really exist, and act according to the laws which we have explained, and abundantly serves to account for all the motions of the celestial bodies and of our sea.

"And now we might add something concerning a certain most subtle spirit, which pervades and lies hid in all gross bodies; by the force and action of which spirit the particles of bodies mutually attract one another at near distances, and cohere if contiguous; and electric bodies operate to greater distances, as well repelling as attracting the neighboring corpuscles; and light is emitted, reflected, refracted, inflected, and heats bodies; and all sensation is excited, and the members of animal bodies move at the command of the will, namely, by the vibrations of this spirit, mutually propagated along the solid filaments of the nerves from the outward organs of sense to the brain, and from the brain into the muscles. But these are things that cannot be explained in few words, nor are we furnished with that sufficiency of experiments which is required to an accurate determination and demonstration of the laws by which this electric and elastic spirit operates."²⁶

set etiam per *substantiam*: nam virtus sine substantia subsistere non potest. In ipso continentur et moventur universa, sed absque mutua *passione*. Deus nihil patitur ex corporum motibus: illa nullam sentiunt resistentiam ex omni-praesentia Dei" (*Principia*, 1713, pp. 482-483).

* "Hactenus Phaenomena caelorum et maris nostri per Vim gravitatis exposui, sed causam Gravitatis nondum assignavi. Oritur utique haec Vis a causa aliqua quae penetrat ad usque centra Solis et Planetarum, sine virtutis diminutione; quaeque agit non pro quantitate *superficierum* particularum in quas agit, (ut solent causae Mechanicae,) sed pro quantitate materiae *solidae*; et cujus actio in immensas distantias undique extenditur, decrescendo semper in duplicata ratione distantiarum.... Rationem vero harum Gravitatis proprietatum ex Phaenomenis nondum potui deducere, et Hypotheses non fingo. Quicquid enim ex Phaenomenis non deducitur, *Hypothesis* vocanda est; et Hypotheses seu Metaphysicae, seu Physicae, seu Qualitatum occultarum, seu Mechanicae, in *Philosophia Experimentalis* locum non habent. In hac Philosophia Propositiones deducuntur ex Phaenomenis, et redduntur generales per Inductionem. Sic impenetrabilitas, mobilitas, et impetus corporum et leges motuum et gravitatis innotuerunt. Et satis est quod Gravitatis revera existat, et agat secundum leges a nobis expositas, et ad corporum caelestium et maris nostri motus omnes sufficiat.

"Adjicere jam liceret nonnulla de Spiritu quoddam subtilissimo corpora crassa pervadente, et in iisdem latente; cujus vi et actionibus particulae cor-

These extracts, together with extracts from subsequent works which we shall meet later, illustrate the neutral position toward the question as to the nature of gravitation which Newton always tried to maintain in his published work, and emphasized in the second and third editions of the *Principia*. We shall only be concerned with the opinions expressed by Newton's school on this subject when we have finished the examination of all that Newton himself has said on it. As we shall see again in the next section, Newton strongly inclined towards the belief that the attraction of matter was brought about by the intermediary of an ethereal medium, but he seems to have rightly recognized that the question as to whether this attraction is, like hardness or impenetrability, an essential property of matter, or whether a medium is necessary for the action of two bodies on one another, had no bearing on the facts about attraction that were mathematically expressed in the *Principia*: it only concerned physical explanations of this attraction. Besides this, it is probable that Newton knew only too well that, by indulging in speculations which could not be proved or disproved experimentally, he laid himself open to hated controversy. It is true that he had to meet controversies about the experimental truths he had discovered; but in the midst of his very natural irritation, he must have been comforted by the thought that, in this case at any rate, there was really no question of personal opinion involved.

V.

Richard Bentley (1662-1742), who became so famous

porum ad minimas distantias se mutuo attrahunt, et contiguae factae cohaerent; et corpora Electrica agunt ad distantias majores, tam repellendo quam attrahendo corpuscula vicina; et Lux emittitur, reflectitur, refringitur, inflectitur, et corpora calefacit; et Sensatio omnis excitatur, et membra Animalium ad voluntatem moventur, vibrationibus scilicet hujus Spiritus per solida nervorum capillamenta ab externis sensuum organis ad cerebrum et a cerebro in musculos propagatis. Sed haec paucis exponi non possunt; neque adest sufficiens copia Experimentorum, quibus leges actionum hujus Spiritus accurate determinari et monstrari debent" (*Principia*, 1713, pp. 483-484).

as a philologist, was, in 1692, nominated first "Boyle lecturer." In the series of lectures which he accordingly gave,²⁷ he tried to present the Newtonian physics in a popular form, and to show that it proved the existence of an intelligent Creator. Indeed, it seems true that, as Rosenberger²⁸ has remarked, England was then the best soil for the growth of the mystical idea of an elementary force directly implanted in matter by God. France and, in part, Germany had adopted the rationalistic philosophy of Descartes, in which all occult forces were banished. Toward the end of the year 1692, Bentley by letter consulted Newton himself, and this was the occasion for the four celebrated replies of Newton, dating from December 10, 1692, to February 25, 1693.²⁹

The first of Newton's letters begins: "When I wrote my treatise about our system, I had an eye upon such principles as might work with considering men for a belief in a Deity; and nothing can rejoice me more than to find it useful for that purpose. But if I have done the public any service this way, it is due to nothing but industry and patient thought." The way in which the solar system is constructed is not, in Newton's opinion, "explicable by mere natural causes," but must be ascribed "to the counsel and countenance of a voluntary Agent." Again: "The same power, whether natural or supernatural, which placed the sun in the center of the six primary planets, placed Saturn in the center of the orbs of his five secondary planets; . . . and therefore, had this cause been a blind one, without contrivance or design, the sun would have been a body. . . . without light or heat. Why there is one

²⁷ "A confutation of Atheism," *The Works of Richard Bentley* (ed. Alexander Dyce), London, 1836, Vol. III. Cf. Brewster, *op. cit.*, 1855, Vol. II, pp. 124-125; Rosenberger, *op. cit.*, pp. 263-265.

²⁸ *Op. cit.*, p. 264.

²⁹ *Horsley*, Vol. IV, pp. 429-442; cf. Rosenberger, *op. cit.*, pp. 265-271. In Brewster's account (*op. cit.*, pp. 125-130) nearly all the points which interest us here are omitted.

body in our system qualified to give light and heat to all the rest, I know no reason but because the author of the system thought it convenient; and why there is but one body of this kind, I know no reason but because one was sufficient to warm and enlighten all the rest. . .” Further, that cause shows itself to be “very well skilled in mechanics and geometry.”

Nearly at the end of the second letter, dated January 17, 1693, Newton³⁰ remarked: “You sometimes speak of gravity as essential and inherent to matter. Pray do not ascribe that notion to me; for the cause of gravity I do not pretend to know, and therefore would take more time to consider of it.” In the fourth letter, he³¹ said: “It is inconceivable that inanimate brute matter should, without the mediation of something else which is not material, operate upon and affect other without mutual contact; as it must do if gravitation, in the sense of Epicurus, be essential and inherent in it. And this is one reason why I desired you would not ascribe innate gravity to me. That gravity should be innate, inherent, and essential to matter, so that one body may act upon another at a distance through a vacuum, without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity that I believe no man who has in philosophical matters a competent faculty of thinking can ever fall into it. Gravity must be caused by an agent acting constantly according to certain laws, but whether this agent be material or immaterial I have left to the consideration of my readers.”

It may be remarked that, as Newton happened to mention, the words: “It is inconceivable. . . .inherent in it” are very nearly Bentley’s own.³² Bentley wrote: “. . .

³⁰ *Horsley*, Vol. IV, p. 437.

³¹ *Ibid.*, p. 438.

³² *Brewster, op. cit.*, Vol. II, p. 466.

should (without a divine impression) operate. . . ." and omitted the phrase: "in the sense of Epicurus."

On this opinion of Newton's, Rosenberger³³ has remarked that a consideration of the context shows that there is only an appearance on Newton's part of a tendency toward a kinetic hypothesis of gravitation; for he added the words "or immaterial," and showed, by his continual emphasis on the necessity there is for an intelligent creator and director of the system of the world, that he, for his part, held that the agent in question was immaterial. Bentley understood Newton's words in this way, and in his lectures laid down without any reserve the proposition that natural actions are brought about by an immaterial agency.³⁴

Newton's fourth and last letter was dated by Horsley February 11, 1693, while the third was dated February 25, 1693. Brewster³⁵ gave February 11 as the date of the third letter, and February 25 as the date of the fourth letter; but what Brewster called (correctly) the third was printed by Horsley as the fourth, and *vice versa*.³⁶ The only letter of Bentley's on this subject which Brewster found among the Portsmouth Papers, was dated February 19, 1693, and obviously Newton's letter of February 25 is a reply to this. Bentley's long letter was printed by Brewster,³⁷ and in it gave at some length his own version of Newton's opinions, stated so that Newton might signify his approval or dissent.

It must be remembered that the introduction of a material medium to serve as a vehicle for the actions between bodies is one of the points of Descartes's philosophy, which

³³ *Op. cit.*, pp. 268-269.

³⁴ Cf. also Whiston's deductions from Bentley's seventh sermon mentioned on page 271 (*ibid.*).

³⁵ *Op. cit.*, 1855, Vol. II, p. 128.

³⁶ The numbering was correctly given in Rosenberger's book.

³⁷ *Op. cit.*, pp. 463-470.

aimed—although the aim was naturally not stated by Descartes at a time when the church was powerful and given to persecution—at the description of the system of nature in rational terms alone, and thus without assuming any intervention of the Deity. Such a scheme would not appeal to the pious Newton, especially as he saw, and expressed in 1687, as we have seen, that an all-pervading fluid of great density—as would seem to be a consequence of its necessary continuity—would offer great difficulties to motion. Indeed, Parmenides, who, in the sixth century before Christ, evolved a primitive cosmology of the same type as that of Descartes, was obliged to put motion in the rank of illusions.³⁸ As might be expected, common sense nearly always dominated logical ideals in men's minds, and the opposition between logical ideals and common sense was slurred over from the time of Zeno till nearly the twentieth century of our era.

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³⁸ Cf. G. Milhaud, *Leçons sur les origines de la science grecque*, Paris, 1893, pp. 208-209; J. Burnet, *Early Greek Philosophy*, 2d ed., London, 1908, pp. 203-208.